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BELLCOMM, INC.

955 L'ENFANT PLAZA NORTH, S.W. WASHINGTON, D.C. 20024

SUBJECT: Accuracy of Radiation Measurements Made on Apollo 8 - Case 340

DATE: February 27, 1969

FROM: R.H. Hilberg

ABSTRACT

Data from some of the Apollo 8 radiation dosimeters reveal some discrepancies among the operational systems on which mission decisions had to be based. The probable cause for these discrepancies was the fact that the dose rates encountered through most of the mission were below the region for which the dosimeters were designed to operate optimally. These dose rates were not significant from a health point of view. In addition, one of the personal dosimeters operated anomalously, reading a dose more than an order of magnitude greater than that which was felt to have been encountered. Post flight examinations suggests that increased care in examining these dosimeters during fabrication could increase their reliability.

While the low dose rate measurements were not especially accurate on a relative basis, there seems to be no problem with dose rates which could be significant to health problems. The only measurements where a dose rate of greater than a few mrad/hr was present occurred during traversal of the trapped radiation belts, and measurements were reasonable in that region.

For potential long duration missions where lower dose rates could become significant, more sensitive dosimetry may become necessary. For Apollo missions of about one week duration there is as yet no indication of inadequacy.

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MEMORANDUM FOR FILE

INTRODUCTION

An extensive array of radiation dosimeters provides operational data for use in the protection of the astronauts from any radiation hazard which might develop. The fact that some of the systems used on Apollo 8 provided inconsistent results raised the question of the reliability of the Apollo dosimetry as well as its adequacy. This memorandum will treat these questions.

In the following sections a number of aspects of the problem of measurement and interpretation of the radiation field are discussed. The description of the dosimeters themselves is based on Reference 1. The discussion of the observations from Apollo 8 is based on References 2 and 3. Information on the calibrations and post flight observations of the dosimeters is based on References 2 and 4.

PREDICTIONS

The doses predicted for the Apollo 8 mission are given in Table 1 (Reference 5). Since no solar particle events occurred, and the Chinese nuclear detonation occurred after the earth orbital phase of the mission, the nominal doses are applicable. The peak trapped dose is of the order of 100 mrad/hr, while the cosmic ray dose is of the order of 1 mrad/hr.

SENSORS

The radiation measuring devices used in the Apollo spacecraft are of two main types: active detectors whose output is available in real time, and passive dosimeters whose data are available only after they are returned to earth and read out in the appropriate manner. Since the active detectors provide essentially the only real time data on which to base operational decisions they will be discussed first.

(NASA-CR-104017) ACCURACY OF RADIATION MEASUREMENTS MADE ON APOLLO 8 (Bellcomm, Inc.) 9 p

N79-73443

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(CODE)

FF No. 6
CR-104017
(NASA CR OR TMX OR AD NUMBER) (CATEGORY)
[redacted]

The Nuclear Particle Detection System (NPDS) is a spectrometer sensitive to heavy charged particles. It is designed to detect protons and alpha particles. It is sensitive to particles in the bands shown in Table 2. It was designed to observe the particles emitted by the sun in solar storms. The readout is through a rate meter for each channel, the threshold and accuracy of which are strong functions of temperature. The active element of the NPDS is a telescope of three junction detectors measuring the particle energy and the rate of energy loss, the combination of which uniquely identifies the particle as well as giving the energy.

The NPDS does not yield the dose directly, but rather measures the particulate environment which enables a computer program to calculate the dose at a variety of points. Data from the NPDS are telemetered directly to the ground. It is located in the service module.

The Van Allen Belt Dosimeter (VABD) is an ionization chamber measuring skin dose rate and 5 cm depth dose rate. Data are telemetered directly to the ground. The information on dose rate is integrated by computer and the total doses read out. The VABD has a threshold of about 10 mr/hr. It was designed for observation of trapped radiation doses, and is also effective for measuring doses from solar particle events.

The Radiation Survey Meter (RSM) is also a rate measuring ionization chamber. It is read out by an astronaut. It has a linear readout in four ranges, .1 rad/hr, 1 rad/hr, 10 rad/hr, and 100 rad/hr, full scale, with a threshold sensitivity somewhat less than 10 mrad/hr. This unit is portable.

Each astronaut was provided with a Personal Radiation Dosimeter (PRD). These dosimeters are ionization chambers which are read out on board. They indicate a total integrated dose in increments of 10 mrad. They were to be worn on the left thigh in a pocket on the Apollo suit.

The Passive Dosimeters consist of a packet of lithium fluoride thermoluminescent powder (TLD), and selected radiation detecting films. The films are being analyzed at the School of Aerospace Medicine. The TLD have been analyzed at MSC.

OBSERVATIONS

The dose observations made by the PRD's and the TLD's are presented in Table 3. The NPDS saw nothing above back-ground. The VABD detected radiation only during the passage of the spacecraft through the trapped radiation belts. The survey meter was read out only once, in the outer fringes of the radiation belts, and indicated a dose rate below threshold (less than 10 mrad/hr).

POST FLIGHT ANALYSIS OF DETECTOR OPERATION

Since the dose rates were expected to be low (about 1 mrad/hr) for most of the mission, the below threshold readings of the VABD and the RSM present no inconsistencies, and these detectors will not be discussed further. The PRDs recorded total doses ranging over two orders of magnitude and required some examination. Since the dose rates encountered were low, measurements were made of PRD efficiency as a function of dose rate, as shown in the figure. It is seen that at a few mrad/hr PRD SN18 has a very low efficiency, while the other two have efficiencies of the correct order of magnitude. For dose rates of the order of 20 mrad/hr or greater the inaccuracies of all PRDs approach 10%. It was also seen that SN18 had a leak rate comparable to several mrad/hr, probably accounting for the low efficiency.

On examination of the PRDs after flight SN10 was seen to have contained two fine aluminum particles about .15" and .1" long inside the ionization chamber dome (Reference 5). While other minor irregularities were uncovered, the presence of these particles seems the most likely reason for the anomalously high readings of this PRD in the zero-g environment.

DISCUSSIONS AND CONCLUSIONS

The instruments flown on Apollo 8 were designed to perform an operational function. They are to provide data needed to protect the health of the astronauts vis-a-vis radiation. In addition the passive dosimeters perform the non-operational function of providing total dose exposure data for each man which becomes available after landing.

Since the skin Mission Operational Dose limit for Apollo 8 was 400 rad for the whole mission (Reference 6), an average dose rate of about 2 rad/hr would be necessary to approach the limit. Considering the depth Mission Operational Dose limit of 50 rad, an average dose rate of about 300 mrad/hr would be necessary. Most of the danger is felt to result from potential solar particle events so that the corresponding dose rates would be higher because of the shorter duration.

The fact that the VABD and the PRDs registered reasonably (except PRD SN10 of course) in the trapped radiation belts suggests that these systems will work well in these higher flux rates.

If the purpose of the instrumentation is to detect hazardous situations rather than provide highly accurate data in the low dose range then there is no indication of inadequacy. A leak rate of a few mrad/hr is insignificant compared to these dose rates. However, the high reading of PRD SN10 is not so insignificant.

It is not clear how the presence of a metallic sliver inside the ionization chamber, if this was indeed the cause of the high readings, will affect the dose reading in a higher radiation field. Therefore the quality control of these instruments may have to be improved.

Further it seems likely that for longer missions (e.g., 1 year) where low dose rates are more critical more sensitive instrumentation may be required.

R H Hilberg

1011-RHH-bl R.H. Hilberg

Attachment
Table 1-3

REFERENCES

1. Richmond, Davis and Lill, "Radiation Dosimetry for Manned Spaceflight," Transactions of the American Nuclear Society. 10#1 p 389, June 1967.

2. T.T. White, MSC/TG-5, Personal communication.

3. S.C. Freden, MSC/TG, Memorandum to FA/Chairman, Radiation Constraints Panel, "Apollo 8 Post Mission Report of the Space Environment Specialists," January 2, 1969.

4. J.R. Bates, Personal communication.

5. W.N. Hess, "Apollo 8 Radiation Environment," presentation to S.C. Phillips, December 4, 1968.

6. NASA - Manned Spacecraft Center - Mission Rules, Apollo 8.

TABLE 1

APOLLO 8 MISSION DOSE ESTIMATES (RAD)

(ALL DOSE ESTIMATES ARE UNCERTAIN BY A FACTOR OF ABOUT 2)

ENVIRONMENT	NOMINAL	CONTINGENCY	REMARKS
DOSE FROM TRAPPED RADIATION BELT FOR NOMINAL TLI AND TEI	0.09(s) 0.01(d)	2.0 (s) 1.0 (d)	NOMINAL: TRAJECTORY FOR DEC. 21, 72° AZM, FIRST LAUNCH OPPORTUNITY CONTINGENCY: MAXIMUM EXPECTED FOR OTHER LAUNCH OPPORTUNITIES OR ALTERNATE MISSIONS.
COSMIC RAY DOSE FOR 7 DAY MISSION	0.08 (s) 0.08 (d)	0.08 (s) 0.08 (d)	
DOSE FROM HIGH ALTITUDE NUCLEAR TESTS	0.0 (s) 0.0 (d)	20 - 200 (s) 1 - 10 (d)	NOMINAL: NO NEW HIGH ALTITUDE NUCLEAR TESTS. CONTINGENCY: ESTIMATES OF THE DOSE RESULTING FROM A NUCLEAR TEST EQUIVALENT TO 10 TIMES STARFISH.
DOSE FROM SOLAR PARTICLE EVENTS	0.0 (s) 0.0 (d)	237 (s) 15 (d)	NOMINAL: NO SOLAR PARTICLE EVENTS ARE EXPECTED. CONTINGENCY: PROTON AND ALPHA DOSES FOR THE NOV. 12, 1960 EVENT. WORST CASE FOR THE PAST SOLAR CYCLE.
TOTAL	0.17 (s) 0.09 (d)		

(s) - DOSE AT A DEPTH IN TISSUE OF 0.07 MM.
(d) - DOSE AT A DEPTH IN TISSUE OF 5 CM.

FROM REFERENCE 5

TABLE 2

ENERGY BANDS DEFINED BY THE NPDS

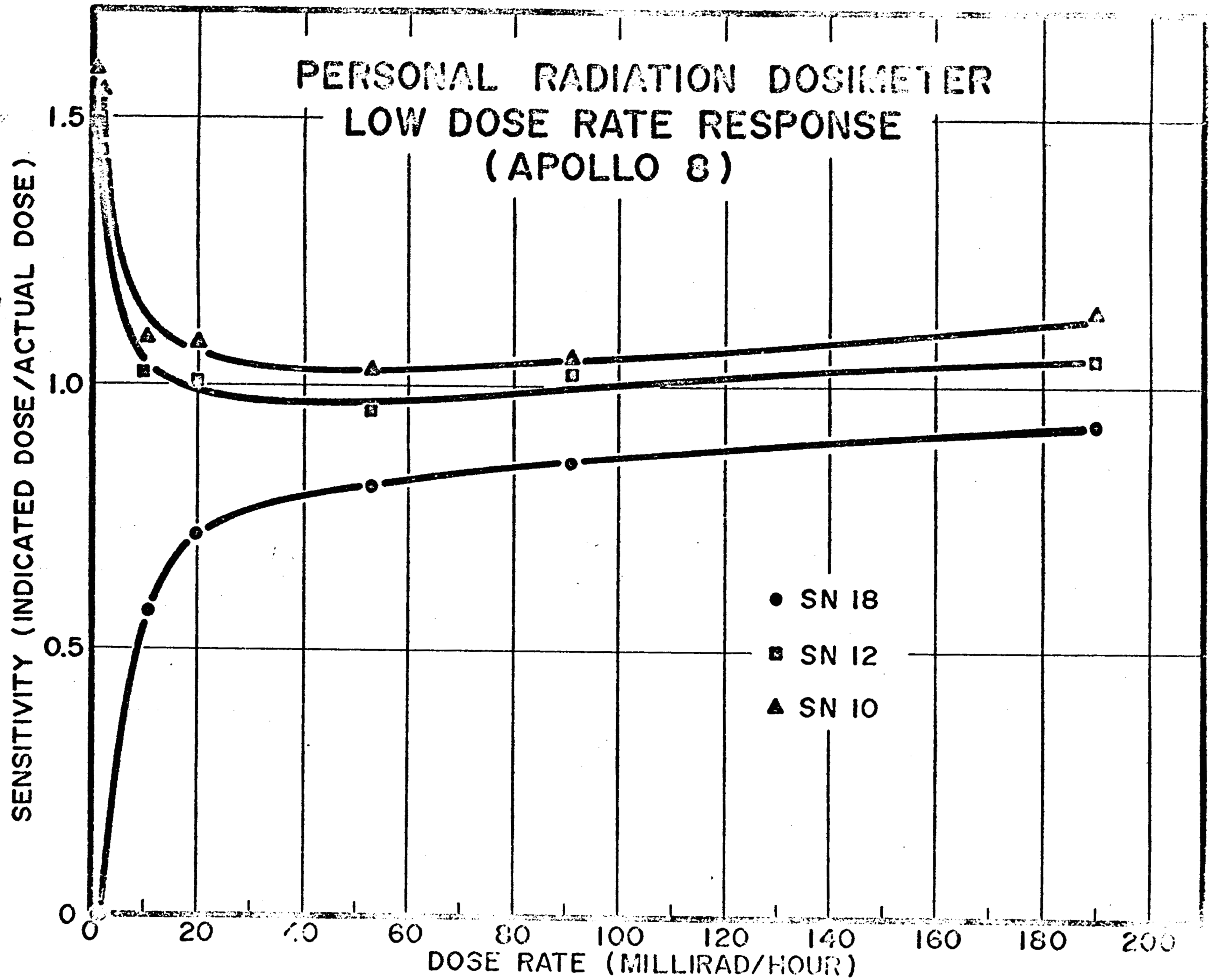
ENERGY BAND	COUNTER RATE RANGE
DIFFERENTIAL - PROTONS	
10 TO 20 MeV	0 TO 100 000 cps
35 TO 45 MeV	0 TO 10 000 cps
85 TO 95 MeV	0 TO 10 000 cps
130 TO 170 MeV	0 TO 10 000 cps
DIFFERENTIAL - ALPHA PARTICLES	
40 TO 50 MeV	0 TO 10 000 cps
130 TO 170 MeV	0 TO 10 000 cps
270 TO 330 MeV	0 TO 10 000 cps
INTEGRAL - PROTONS ONLY	
$\geq$ 15 MeV	0 TO 100 000 cps

TABLE 3

APOLLO 8 RADIATION MEASUREMENTS

DETECTOR		TOTAL MISSION SKIN DOSE (RAD)
PERSONAL RADIATION DOSIMETER*		
SN10 (LM PILOT)		3.31
SN12 (COMMANDER)		0.19
SN18 (CM PILOT)		0.01
THERMOLUMINESCENT DETECTORS		
COMMANDER -	ANKLE	.141
	THIGH	.155
	CHEST	.152
CM PILOT	ANKLE	.154
	THIGH	.177
	CHEST	.157
LM PILOT	ANKLE	.140
	THIGH	.133
	CHEST	.140
FILM BOX		.180
VAN ALLEN BELT DOSIMETER		.230

*AT 61:09 THE PRDS WERE SWITCHED AS FOLLOWS: SN12 TO CM PILOT SN18 TO LM PILOT, SN10 TO COMMANDER. SN18 HAD A READING OF .64 RAD BEFORE LAUNCH AND .65 RAD AFTER RETURN.


PERSONAL RADIATION DOSIMETER
LOW DOSE RATE RESPONSE
(APOLLO 8)
SENSITIVITY (INDICATED DOSE/ACTUAL DOSE)
1.5
1.0
0.5
0
0
20
40
60
80
100
120
140
160
180
200
DOSE RATE (MILLIRAD/HOUR)
SN 18
SN 12
SN 10